NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 42, 2025
www.incda-fundulea.ro; doi.org/10.59665/rar4237 First Online: March, 2025. DII 2067-5720 RAR 2025-24

Cultivar and Environment on the Impact of Yellow Rust (*Puccinia striiformis*) in Triticale

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ABSTRACT

Yellow (stripe) rust caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*) is a major destructive fungal disease of triticale, of increasing importance in recent years, in Romania and worldwide.

We tested twenty-three released triticale cultivars and breeding lines originated from the breeding program of NARDI Fundulea and twenty-five new lines selected at ARDS Teleorman in locations with higher stripe rust attack in 2023 and 2024, and observed significantly different disease scores, ranging from resistant to very susceptible. In five yield trials performed in 2023 and 2024, stripe rust had significant impact on grain yield explaining between 15 and 92% of the yield variation. In one trial, at Târgu Mureș the disease occurred unusually early and intense on young plants, and susceptible cultivars did not produce any yield. On average over six trials (three locations x two years) the correlation between rust scores and grain yield was r=- 0.84*. Best resistance to *Puccinia striiformis* was observed in cultivar Zaraza and in five of the new lines. Based on genealogy, we could trace the resistance sources, to the Polish semidwarf cultivar Magnat and to introgressions from *Triticum aestivum* cultivars which were used as parents in crosses with triticale. The deployment of disease-resistant host cultivars proved to be an efficient, economically, and environmentally sound approach to control yellow rust.**

We observed large yield differences between cultivars scored similarly for rust attack, suggesting differences in partial resistance and/or tolerance to the disease. Their exploitation can be, along with exploiting available sources of strong resistance genes, an additional breeding objective for reducing rust induced yield losses.

The impact of stripe rust on yield was associated with lower temperatures and higher rainfall in April, which explained more than one third of the variation in coefficients of correlation between stripe rust and yield.

Keywords: stripe rust, triticale, resistance, grain yield, tolerance.

INTRODUCTION

Triticale (×*Triticosecale* Wittmack), a synthetic intergeneric hybrid between wheat (*Triticum* sp.) and rye (*Secale* sp.) has gained considerable importance in the past decades. It combines desirable traits of both parents (Salmanovicz et al., 2013), the high yield potential and high grain protein content of wheat with the disease resistance and environmental tolerance of rye to abiotic stress conditions such as aluminum toxicity, drought, salinity, acidic or waterlogged soils (Kuleung et al., 2004). Triticale is especially used for food or forage but holds potential for human nutrition and industrial use (e.g., fuel production, bio composite materials, alcohol etc.). Triticale constitutes a valuable genetic resource for transferring genes of interest from rye into wheat, particularly those related to biotic and abiotic stresses (Arseniuk, 1996; Vaillancourt et al., 2007; Săulescu et al., 2011; Kumar et al., 2014).

Triticale was long considered very resistant to rusts (Schevchenko and Karpachev, 1985) but later, several rust epidemics caused by *Puccinia* species have been reported in triticale (Bekele et al., 1985; Haesert et al., 1987; Wilson and Shaner, 1989; Iliev et al., 1990; Zwer et al., 1992; Zamorski, 1994; Schinkel, 2002; Sodekiewicz and Strzembicka, 2004; Mergoum et al., 2009; Mikhailova et al., 2009). Among these, yellow (stripe) rust (*Puccinia striiformis*,

Received 8 September 2024; accepted 14 March 2025.

Pst), emerged in the past decades as a real economic threat in triticale (Wiese, 1987; Singh and Saari, 1991; Guedes-Pinto et al., 1996).

A race of Pst more aggressive on triticale, described as part of *Pst S13* group, first discovered in Europe in 2006 on the island of Bornholm, has become common in widely grown triticale varieties, first in Germany and Scandinavia (Hovmøller et al., 2016; Župunski et al., 2023). Although the race belongs to *P. striiformis* sp. *tritici*, it has never been found on winter wheat varieties in Europe. This aggressive triticale race led to yield losses of up to 100% in Scandinavia, where controlling triticale epidemics in organic production has proven challenging. It is worth noting that Pst races Warrior and Kranich, which caused significant wheat yield losses in Europe since 2011, were also detected on triticale. During the 2022/2023 growing season, yellow rust was recorded on triticale in Serbia for the first time at Rimski Šančevi in Vojvodina, a North Province of Serbia (Jevtić et al., 2023).

In Romania, *Pst*, which is generally more adapted to the humid and cooler environments (3°C - 15°C), occured rather sporadicaly in the past (Ittu et al., 1989) and was rarely seen on triticale. However, a 91,7% attack of *Pst* on untreated plots of triticale was registered in 2018 (Goga, 2019) and attacks varying from 10 to 90% were reported on triticale in Western Romania (Cotuna et al., 2019, 2023). In 2023 symptoms of disease were observed on triticale in 2023, even in the South of Romania since March (Voica et al., 2023), and heavy attacks were reported in triticale in North-West and in Transylvania (Galit et al., 2023). Results presented by Galit et al. (2023) suggested that the stripe rust races present in 2023 were better adapted to higher temperatures.

MATERIAL AND METHODS

Triticale released cultivars and breeding lines originating from the breeding program of NARDI Fundulea were tested in 2022-2023 and 2023-2024 seasons in yield trials with balanced square lattice design with twenty-five entries and three replications, on five or ten m^2 harvestable plots without irrigation and using the usual crop management. Out of the eight locations which performed the trials, in three locations stripe rust was strong enough to have impact on grain yield, as expressed by a correlation between disease scores and yield r>0.3 in at least one year. These locations included ARDS Livada (47°52’N latitude - 23°08’E longitude), RDSB Târgu Mureş (46°32’N latitude - 24°33’E longitude) and ARDS Teleorman (44°07’N latitude - 25°45’E longitude). We included in the analysis twenty-three cultivars which were tested in both years.

In 2023-2024 at Târgu Mureş and Teleorman preliminar yield trials with one replicat ion, including new lines selected at ARDS Teleorman were organized in the same conditions.

Intensity of *Puccinia striiformis* was visually scored in the field under natural infection and uncontrolled conditions, on a scale between 1-9, where 1 (resistant) and 9 (susceptible) (McNeal et al., 1971) and grain yield was expressed as kg ha^{-1} at 14% moisture.

Data obtained in this study were statistically analyzed by ANOVA. The relation between attack of *Pst* and grain yield was calculated for each of six trials (three locations x two years) and between the scores registered in each locations, based on *Pearson* coefficients of correlations and linear regressions.

Weather data from weather stations nearest to the yield trials were collected and analyzed. We present here only data on average temperatures and rainfall during the spring months, as most related to the development of stripe rust epidemic. As seen in Table 1, spring weather conditions showed large variations, both between the three locations (with Târgu Mureş being the coolest and more humid and Teleorman having higher temperatures and less rainfall) and between years (2024 being warmer and dryer).

Table 1. Average temperatures and rainfall at three locations in 2023 and 2024

Specification		Livada		Târgu Mureș		Teleorman	
Month	Decade	Temp. (°C)	Rainfall mm	Temp. (°C)	Rainfall mm	Temp. (°C)	Rainfall mm
March 2023	I	5,4	4.0	7.2	9.0	6.1	6.0
	II	5,9	14.2	7,2	12.5	6.4*	10.0
	III	7,9	8.9	9,4	208.2	7.8	8.0
	Mean/Sum	**6,4**	**27.1**	**7,9**	**229.7**	**6,8**	**24.0**
April 2023	I	6,4	20.4	8,2	22.7	5.2	36.0
	II	11,6	9.8	12,0	6.8	11.1	10.0
	III	10,9	43.1	13,0*	29.5	11,0	9.0
	Mean/Sum	**9,6**	**73.3**	**11,1**	**64.0**	**9,1**	**55.0**
May 2023	I	14,4	6.3	14,3*	8.0	13,5	8.0
	II	15,2	10.9	15,9	5.0	15.2	5.5
	III	19,4	2.5	18,4*	15.5	18.4	40.5
	Mean/Sum	**16,3**	**19.7**	**16,2**	**28.5**	**15,7**	**54.0**
March 2024	I	9.2	9.8	8.98	15.0	7.0	3.0
	II	7.5	15.2	6.77	30.0	7.4	27.5
	III	11.2	15.0	11.1	5.0	11.3	19.0
	Mean/Sum	**9.3**	**40.0**	**9.0**	**50.0**	**8.6**	**49.5**
April 2024	I	14.8	9.0	14.6	3.0	15.7	2.0
	II	12.5	16.5	13.6	31.0	16.1	13.0
	III	12.1	16.1	12.1	32.0	13.4	19.0
	Mean/Sum	**13.1**	41.0	**13.4**	**66.0**	**15.1**	**34.0**
May 2024	I	17.3	8.4	16.1	22.0	15.7	12.5
	II	15.9	6.5	14.7	21.0	15.0	4.5
	III	19.1	15.3	17.7	18.0	19.0	15.0
	Mean	**17.4**	**30.2**	**16.1**	**61.0**	**16.6**	**32.0**

Temperatures higher than optimum for pathogen development.

RESULTS AND DISCUSSION

Cultivars and environments were significant sources of variation for both stripe rust scores and grain yield in the analyzed Triticale trials (Table 2).

Table 2. ANOVA for stripe rust score and grain yield in the six analyzed yield trials

Source of Variation	df	Stripe rust score MS	Stripe rust score F	Grain yield MS	Grain yield F	F crit
Cultivars	22	6.570	5.038	5386448	5.887	1.639
Environments	5	159.176	122.060	1.54E+08	168.078	2.296
G*E interaction	110	1.304		914853.8		

We noticed that stripe rust scores from all trials, except those from Teleorman in 2024 where rust was practically absent, were significantly correlated (Table 3). This suggest that the stripe rust virulence present in all locations where the attack was severe was similar as was the virulence present in both years, as cultivar classification remained mostly unchanged in all trials, except that at Teleorman in 2024.

Table 3. Correlation between stripe rust scores registered in the six analyzed trials

	Livada 23	Livada 24	Târgu Mureş 23	Târgu Mureş 24	Teleorman 23	Teleorman 24
Livada 23	1					
Livada 24	**0.52**	1				
Târgu Mureş 23	**0.62**	**0.81**	1			
Târgu Mureş 24	**0.47**	**0.52**	**0.55**	1		
Teleorman 23	**0.58**	**0.49**	**0.51**	**0.62**	1	
Teleorman 24	0.37	0.24	0.32	0.29	-0.09	1

Figures 1 to 3 present the relationship between stripe rust attack and grain yield in the six trials, highlighting the differences between tested cultivars and differences between the results obtained in years 2023 and 2024.

At Târgu Mureş in 2023 the attack was very strong, reducing the yield of most susceptible cultivars to zero and causing the highest correlation between stripe rust and yield (r=-0.92***). In 2024, the stripe rust attack was not so strong, but still caused a very significant correlation (r=-0.86***) between stripe rust scores and grain yield (Figure 1). Cultivar Zaraza was the most resistant and produced the highest yield.

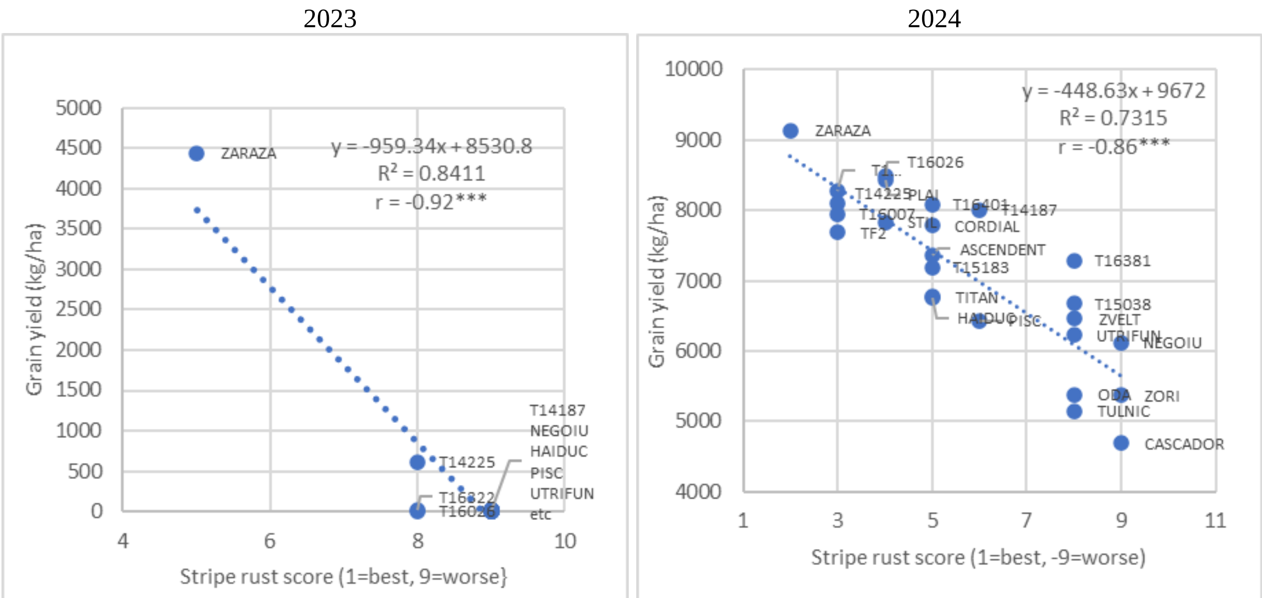

Figure 1. Relationship between stripe rust attack and grain yield at Târgu Mureş

At Livada, both in 2023 and 2024, stripe rust attack was a little milder, but still causing significant correlations of 0.65** and 0.70** with grain yield (Figure 2). Cultivar Zaraza was again the most resistant and the highest yielding of all tested cultivars.

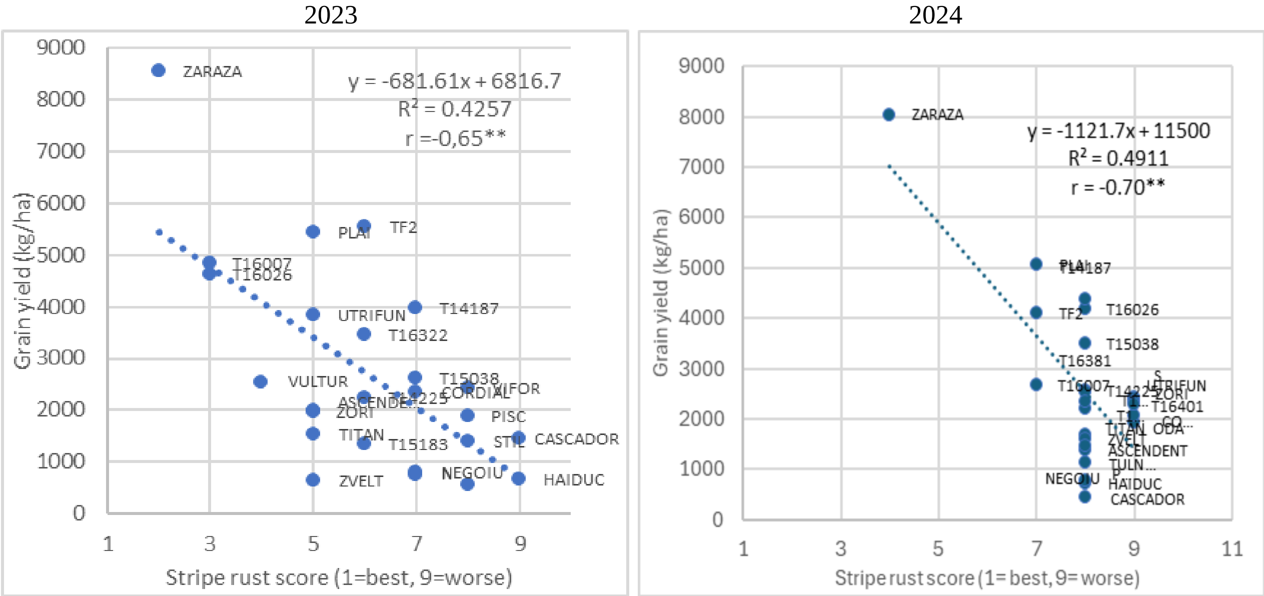

Figure 2. Relationship between stripe rust attack and grain yield at Livada

At Teleorman in 2023, stripe rust attack was less evident, causing a correlation of only r=-0.39 and explaining about 16% of the total grain yield variation. In contrast, in 2024 stripe rust scores were not correlated with yield. Many cultivars were scored along with Zaraza without stripe rust in the field, and the line T14187 produced the highest yield despite showing higher stripe rust attack (Figure 3).

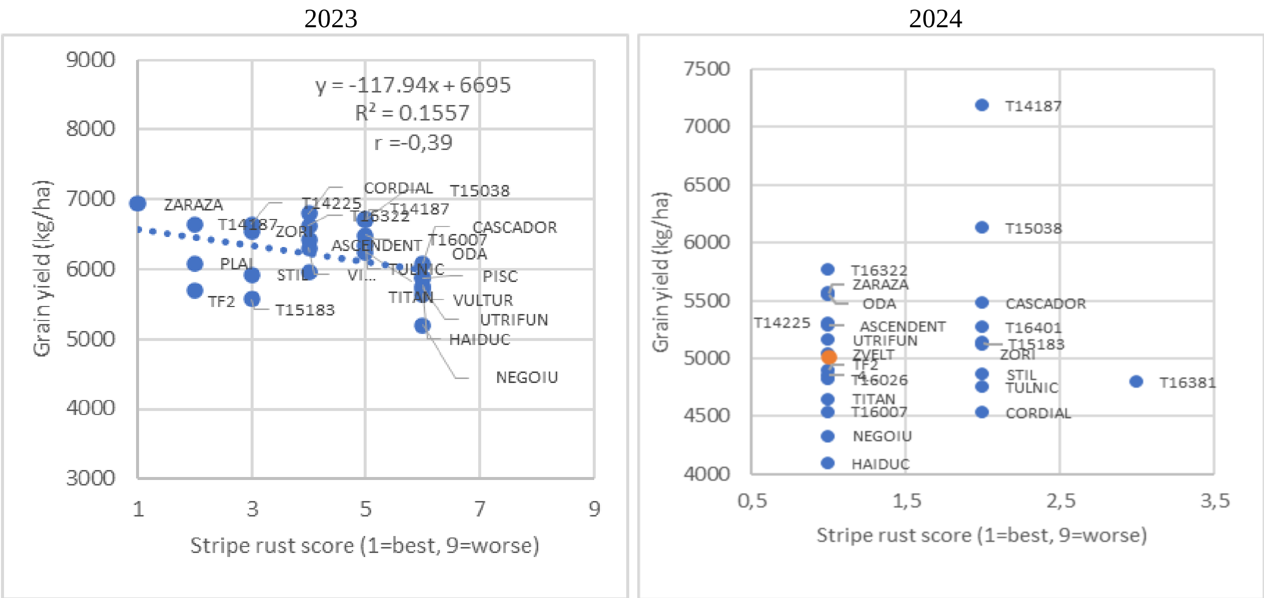

Figure 3. Relationship between stripe rust attack and grain yield at Teleorman

On average over the six analyzed yield trials (3 locations x 2 years), Zaraza was significantly better than any other cultivars both for stripe rust resistance and yield (Table 4). It also had the most stable performance for both stripe rust md grain yield, as estimated by the lowest variance of the corresponding data.

The rest of studied cultivars could be grouped into two groups, one with average stripe rust scores lower than 5 and average yields higher than 4200 kg/ha (which included cultivars T16026, T16007, TF2, Plai and T14225), which can be considered as medium susceptible and the other with average scores higher than 5, which can be considered as susceptible and included the rest of studied cultivars. One can notice that this later group includes most of the released cultivars, except for two older cultivars, TF2 and Plai.

Table 4. Stripe rust scores and grain yield of twenty-three triticale cultivars, averaged over six trials (3 locations x 2 years)

Stripe rust score		
Cultivar	Averaged over six trials	Variance
Zaraza	2.5	2.7
T16026	4.3	9.1
T16007	4.5	7.1
TF2	4.7	9.9
Plai	4.8	7.8
T14225	4.8	8.6
T16322	5.0	8.0
FDL Ascendent	5.3	8.3
Titan	5.5	7.9
T15183	5.5	7.5
Stil	5.8	10.2
Zvelt	5.8	9.4
FDL Cordial	6.0	8.0
Zori	6.2	10.6
T14187	6.2	6.2
Haiduc	6.3	9.5
Pisc	6.3	8.3
Utrifun	6.3	9.5
T15038	6.5	6.7
Negoiu	6.7	9.1
Oda FD	6.7	9.1
Tulnic	6.7	7.1
Cascador	7.2	7.8
LSD 5%	1.36	

Grain yield (kg/ha)		
Cultivar	Averaged over six trials	Variance
Zaraza	7113	3323765
T14187	5046	8576397
Plai	4999	7664827
T16026	4797	8070712
TF2	4658	6577465
T16007	4409	8016503
T16322	4396	9331511
T15038	4277	7327029
T14225	4245	8347209
FDL Cordial	3918	8998532
Utrifun	3898	5528266
FDL Ascendent	3745	9068583
Stil	3732	8889848
T15183	3595	7772520
Zori	3563	6235490
Titan	3480	7784520
Pisc	3366	7248143
Zvelt	3283	8171507
Oda FD	3254	7044529
Tulnic	3032	7295462
Cascador	3023	7304757
Haiduc	2983	8355543
Negoiu	2876	6961149
LSD 5%	1138	

The graphical representation of the relationship between the average stripe rust scores and grain yield illustrates the outstanding performance of cultivar Zaraza and highlights the close correlation (r=-0.84***) between the level of stripe rust attack and yield in the studied yield trials (Figure 4). It also illustrates the fact that there are large yield differences between cultivars that have same rust scores. The most obvious is the case of cultivar T14187 which ranked second for yield while scored with 6.2 for stripe rust and yielded much more than expected based on the general regression of yield on rust scores. Deviations from this regression can be considered as estimations of partial resistance or tolerance to stripe rust attacks, which could be another valuable tool in controlling rust damage, along with resistance. Ashmawyet et al. (2024) showed that cultivars classified as slow-rusting (partially resistant) cultivars, having longer incubation and latent periods, along with smaller stripe lengths and lower infection frequencies, had lower yield losses and more durable protection against stripe rust.

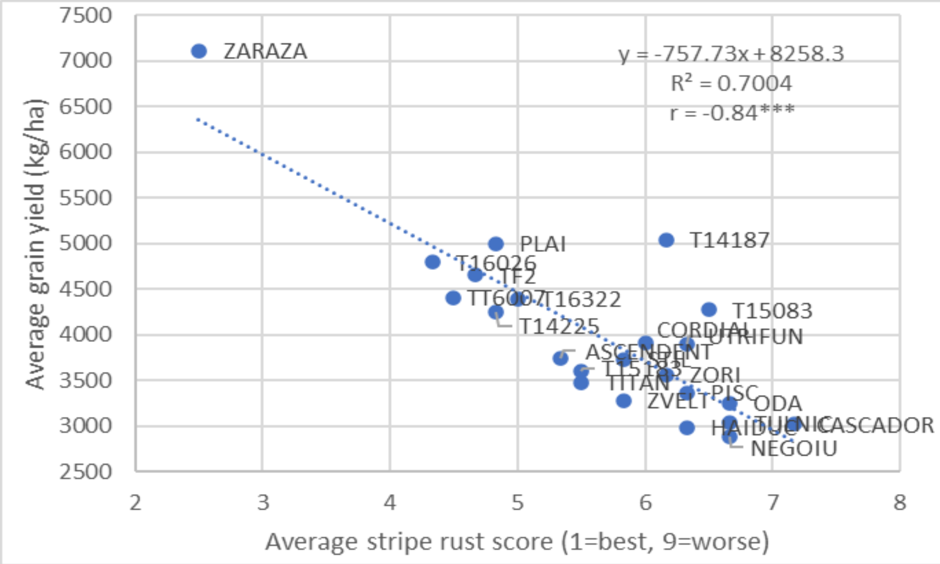

Figure 4. Relationship between stripe rust attack and grain yield averaged on six yield trials

As seen from Table 5, which presents the deviations from regression in the five trials where regressions explained more than 15% of the yield variation, we observed significant differences among the studied cultivars. Cultivars Zaraza and T14187 showed positive average deviations from regression larger than 1 ton/ha, and cultivars Plai and T15038 had deviations larger that 500 kg/ha.

In contrast, cultivars Tulnic, Haiduc, Titan, Negoiu and Zvelt produced less than expected based on the regression of yield on stripe rust scores, by more than 500 kg/ha.

Table 5. Deviations from the regression of grain yield on stripe rust score (kg/ha)

Cultivar	Yield trial					
	Livada 2023	Târgu Mureş 2023	Teleorman 2023	Livada 2024	Târgu Mureş 2024	Average (kg/ha)
Zaraza	3100	707	359	1034	362	1112
T14187	1921	130	607	1857	1024	1108
Plai	2024	84	-377	1413	553	739
T15038	575	121	614	974	591	575
TF2	2811	127	-760	453	-637	399
FDL Cordial	304	90	578	652	353	396
T16026	-155	-844	188	1668	612	294
Utrifun	443	125	-260	995	145	290
Stil	27	56	-412	1013	-40	129
T16322	740	-833	408	-309	-49	-9
Zori	-1431	119	208	943	-260	-84
T14225	-483	-236	308	31	-228	-122
Pisc	517	126	-111	-1390	-553	-282
Oda FD	-1282	111	-99	527	-701	-289
T16007	84	-914	386	-974	-372	-358
Cascador	761	103	101	-2088	-945	-414
FDL Ascendent	-1404	50	204	-1077	-71	-460
T15183	-1373	86	-767	-192	-241	-497
Tulnic	-806	96	239	-1135	-932	-508
Haiduc	-23	126	-348	-1800	-674	-544
Titan	-1875	112	141	-848	-659	-626
Negoiu	-1242	127	-788	-1741	482	-633
Zvelt	-2766	108	-269	-928	378	-695
					LSD 5%	248

The major differences observed between the analyzed yield trials in the impact of stripe rust on Triticale yield can have several explanations, such as inoculum availability, plant nutrition etc., but first are due to the weather conditions. Among the weather conditions that we investigated, average April temperature and rainfall and their ratio explained more than one third of the impact of stripe rust on yield, more than any other analyzed weather parameter (Table 6).

Table 6. Correlations between weather data and the impact of stripe rust on Triticale yield (estimated by the correlation between stripe rust score and grain yield)

Month	Average temperature (°C)	Rainfall (mm)	Ratio Rainfall/Temperature
March	0.24	0.26	0.19
April	0.61	-0.76	-0.67
May	0.28	-0.25	0.27

The computed correlations indicate that lower temperature and higher rainfall in April increased the impact on stripe rust on Triticale yields. If forecasts of future climate changes seem to reduce on average the stripe rust impact on yield, climate changes are also associated with increased variability and that could increase chances of severe stripe rust attacks with important effects on yield.

In 2024 new triticale lines selected at ARDS Teleorman were tested in preliminary yield trials at Târgu Mureş and Teleorman. At Târgu Mureş stripe rust was severe, allowing a good differentiation of the lines, with rust scores from 1 to 9 and corresponding grain yield from 9000 kg/ha to 5100 kg/ha. Correlation between stripe rust scores and yield was 0.67** (Figure 5). Selection performed at Teleorman in 2023, even if stripe rust attack was only moderate, allowed promoting lines, such as TR24-17, TR24-10, TR24-4 and TR24-5, with excellent resistance.

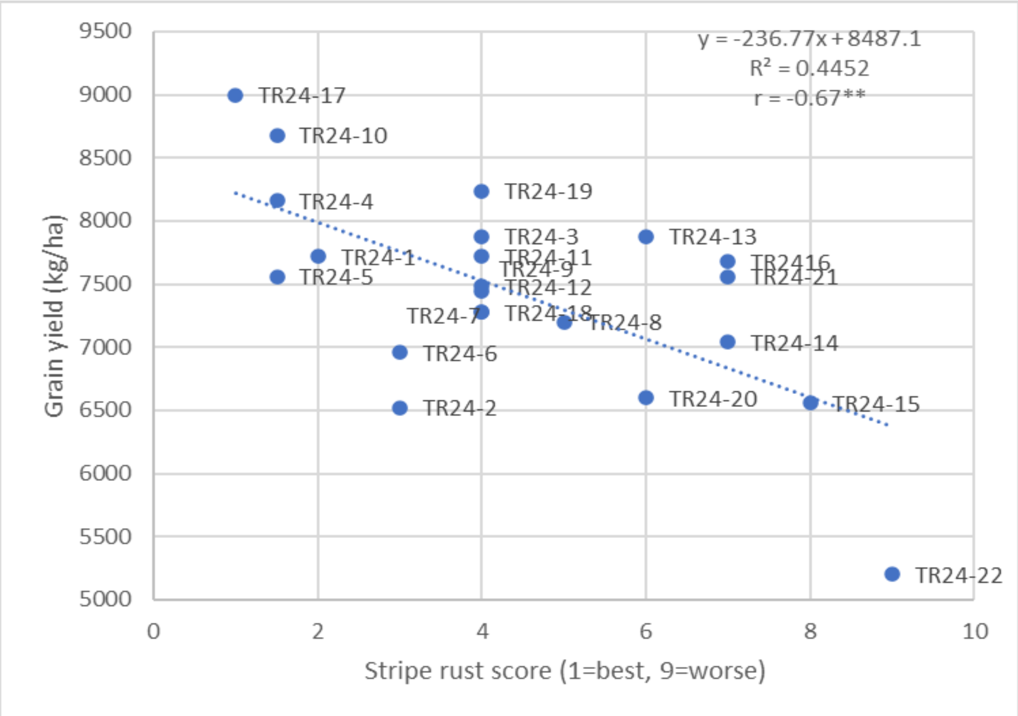

Figure 5. Relationship of stripe rust scores and grain yield in preliminary yield trials with Triticale lines selected at ARDS Teleorman

In contrast, at Teleorman stripe rust was almost absent and comparing yields obtained at Târgu Mureş and Teleorman allowed an estimation of performance in the presence or absence of this disease (Figure 6).

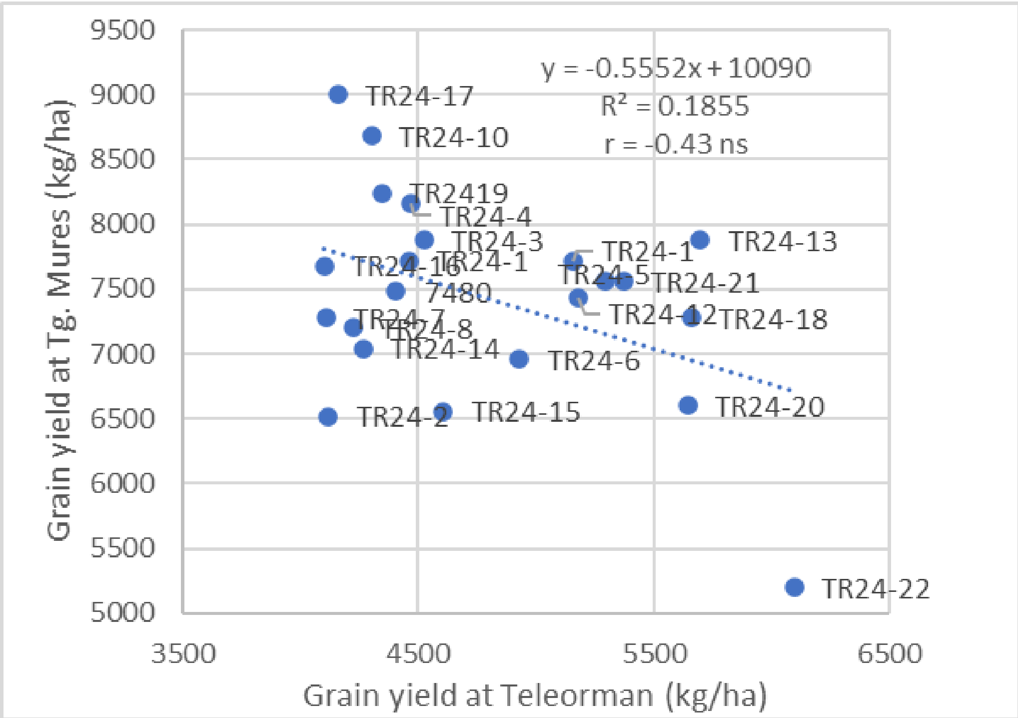

Figure 6. Comparison between yields obtained in preliminary yield trails at Teleorman and Târgu Mureş by new lines selected at ARDS Teleorman

One can easily observe from the figure that lines such as TR24-17 and TR24-10 combine a reliable performance in the dry and hot environment of Teleorman with superior results in a cooler and more humid environment which promoted stripe rust at Târgu Mureş.

Based on genealogy we could trace the resistance to stripe rust sources in the best cultivars and lines to the Polish semidwarf triticale cultivar Magnat and other triticale lines from Danko (Banaszak, 2011), which are present in the genealogy of Zaraza, TR24-17, TR24-7, TR24-4 and possibly to introgressions from common wheat (*Triticum aestivum*) cultivars, used in crosses with Triticale. Having in mind the fast evolution of *Puccinia striiformis* virulence it is imperative to consider further diversification of resistance genes in the Romanian Triticale breeding programs.

Data presented in this paper demonstrate that stripe (yellow) rust (*Puccinia striiformis*) can have disastrous effects in Triticale, reducing yields to zero in susceptible cultivars and in environments that favor the disease. Even under the highest attacks resistant cultivars could prevent severe yield losses.

Resistant entries were rare in the analyzed trials, with only one resistant entry in the National yield trial and more in the preliminary trial, as a result of selection performed at ARDS Teleorman in 2023. Further breeding efforts are needed to increase the share and diversity of Triticale stripe rust resistant germplasm in Romania.

Analyzed Triticale cultivars showed major differences in deviations from regression of yield on stripe rust score, which can indicate partial resistance, slow rusting, or tolerance to the disease. Exploiting these differences in breeding can provide an additional way of protecting Triticale yields from yield losses caused by stripe rust.

CONCLUSIONS

Twenty-three triticale cultivars and twenty-five new lines tested in locations with high stripe rust attack in 2023 and 2024 showed significantly different disease scores, ranging from resistant to very susceptible. Best resistance to *Puccinia striiformis* was observed in cultivar Zaraza and in five of the new lines. In five yield trials performed in 2023 and 2024, stripe rust had significant impact on grain yield explaining between 15 and 92% of the yield variation and in one trial susceptible cultivars did not produce any grains.

We observed large yield differences between cultivars scored similarly for rust attack, suggesting differences in partial resistance and/or tolerance to the disease. These differences suggest that their exploitation can be, along with exploiting available sources of strong resistance genes, an additional breeding objective for reducing rust induced yield losses,.

The impact of stripe rust on yield was associated with lower temperatures and higher rainfall in April, which explained more than one third of the variation in coefficients of correlation between stripe rust and yield.

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